ECOSYSTEM STATUS INDICATORS

Forage Fish

Exploring Links between Ichthyoplankton Dynamics and the Pelagic Environment in the Northwest Gulf of Alaska.

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The impact of climate on marine fisheries is highly variable, and year-to-year recruitment is subject to a complex interplay of influences. Potentially, much of this complexity stems from the impact of environmental conditions during the early life history of marine fish species. The present study focuses on a 21-year time-series of larval fish abundance in late-spring surveys from 1981 through 2003 in the northwest Gulf of Alaska. In combination with basin and local-scale measures of the state of the atmosphere and ocean in the Gulf of Alaska during these years, links between fish early life history dynamics and the physical environment are explored. Interannual variation in the observed abundance of ichthyoplankton species in this area may reflect interannual variation in the timing and quantity of local egg and larval production, egg mortality, larval survival and growth, and the transport of eggs and larvae into and out of the study area. It is hypothesized that these early life history dynamics are species-specifically linked to unique combinations of environmental variables.

Ichthyoplankton data were selected from an area and time (May 16-June 6) that had the highest sampling density and the most consistent sampling over the years. Numerically dominant species were used in the analysis (Table 8). The environmental data time-series includes climate indices, and atmospheric and oceanographic variables representative of both the broader basin of the Gulf of Alaska and northeast Pacific Ocean, and the local study area (Table 9). The influence of environmental conditions on the abundance and survival of various species of fish larvae is likely to be significant from the initial production of the eggs (predominantly winter to early spring in the Gulf of Alaska) through the period of late larval development, weeks to months later. Consequently, both time-lagged and survey time values of the environmental time-series were included in the analysis (Table 9). Relationships between larval fish abundance and environmental factors were examined using Generalized Additive Modeling (GAM). GAM is a form of non-parametric multiple regression that models a response variable as a function of several predictor variables. For each group of environmental variables (basin and local-scale), GAMs were run for individual species with every possible combination and subset of variables. Best-fit models were selected using generalized cross validation methods (Green and Silverman, 1994).

For the time-series, unique patterns of periodicity and amplitude of variation in abundance are apparent among species (Table 10). Some commonality is observed, especially for the deepwater spawners (northern lampfish, arrowtooth flounder and Pacific halibut) that display a decadal trend of enhanced abundance during the 1990s. Species-specific seasonality is apparent in the associations between late spring larval abundance and environmental variables (Table 10). There is, however, a general trend indicating that basin-scale environmental conditions in February through April, and local-scale conditions in late-March through early-April, are most influential in terms of prevalence of larvae in late spring. Observed species-specific patterns of association between late spring larval abundance and environmental variables seem to reflect geographic distribution and early life history patterns among species. For example, the deepwater spawners arrowtooth flounder and Pacific halibut show a common, strong connection with the Shelikof water transport variables (FLOWKL8 and RI) that probably reflects their dependence on advection onto the shelf, and retention processes in this area, for successful larval survival. Another example is the opposite response of northern and southern rock sole to the temperature variables, reflecting their different geographical distributions. Further work continues at the individual species early life history level to investigate potential mechanisms underlying the observed links between species and environmental variables. This type of ichthyoplankton time-series study shows good potential for identifying levels of resilience or vulnerability of individual species early life history patterns to fluctuating oceanographic conditions.

Table 8. Numerically dominant species of fish larvae included in the study, ranked according to percentage occurrence in the study area for all years combined.

Species	**Common name**	**% Occurrence**	**Mean abundance (no./10m^2)**
Theragra chalcogramma	Walleye pollock	90.18	362.11
Hippoglossoides elassodon	Flathead sole	76.57	50.01
Ammodytes hexapterus	Pacific sandlance	75.15	33.38
Bathymaster spp.	Ronquils (genus *Bathymaster*)	66.43	99.42
Gadus macrocephalus	Pacific cod	49.78	14.65
Lepidopsetta polyxystra	Northern rocksole	35.05	5.29
Stenobrachius leucopsarus	Northern lampfish	33.03	5.88
Sebastes spp.	Rockfishes	30.99	29.03
Lepidopsetta bilineata	Southern rocksole	20.55	2.77
Atheresthes stomias	Arrowtooth flounder	18.79	7.32
Platichthys stellatus	Starry flounder	18.56	3.24
Hippoglossus stenolepis	Pacific halibut	10.00	1.07

Table 9. Environmental variables included in analysis (abbreviation on left), and source of data.

Basin Scale Variables

	Monthly	**Source**
CUI	Coastal Upwelling Index at 60 N 155.5 W	NOAA / PFEL
FRESH	GOA River Discharge	Tom Royer
SST1	Sea Surface Temperature (SST) 57.5N,155.5W	NOAA / NCEP Reanalysis
SST2	Sea Surface Temperature (SST) 57.5N,149.5W	NOAA / NCEP Reanalysis
PDO	Pacific Decadal Oscillation (Leading PC of SST)	Mantua et al. 1997
NPI	North Pacific Index (sea level pressure)	Trenberth and Hurrell 1994
MEI	Multivariate ENSO Index	NOAA / CDC
	Preceding Winter	
PDOw	1st Leading Principal Component for Winter (Nov-Mar) SST	Bond et al. 2003
VICw	2nd Leading Principal Component for Winter (Nov-Mar) SST	Bond et al. 2003

Local Scale Variables

	Semi-monthly (observed)	**Source**
ALONG	Alongshore Wind Index	
UPWELL	Upwelling-favorable Wind Index	Stabeno et al. 2004
MIXING	Wind Mixing Index (wind speed cubed)	
SSTanom	Normalized SST anomalies, Shelikof, based on 1950-2003 mean	NOAA / NCEP Reanalysis
	Seasonal (observed)	
T90	Shelikof temperature below 90 m, Feb-Apr mean	NOAA/AFSC; Jennifer Boldt
	Semi-monthly (model-derived)	
FLOWKL8	Flow through Line 8, Kodiak side	Hermann and Stabeno 1996; Computed from the SPEM model
RI	Retention Index (Percent particles released in upper 100m of study area not lost to advection in 14 days)	Hermann and Stabeno 1996; Computed from the SPEM model

Table 10. Late spring (May 16-June 6) time series of normalized larval fish abundance anomalies (column one) and significant environmental variables in best fit GAMs (with R^2 (adj.)>0.50) of late spring larval abundance versus time-lagged independent variables (columns two and three). Best fit GAMS were selected based on the following objective criteria; an R^2 (adj.) value >0.50 in combination with the highest percentage of deviance explained, and the lowest P-values for the individual variables in the model. Empty cells denote variables that did not emerge in the best fit GAMs.

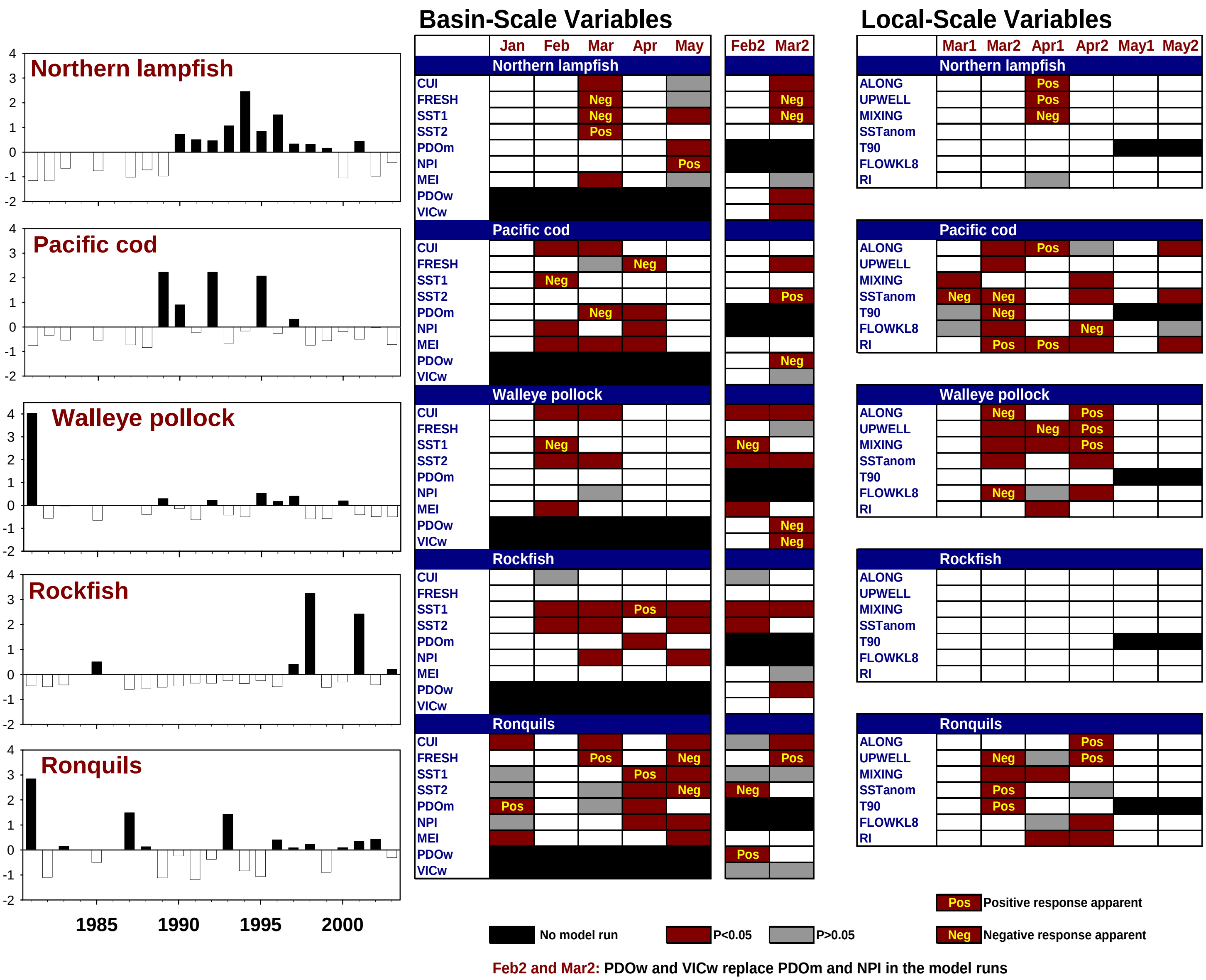
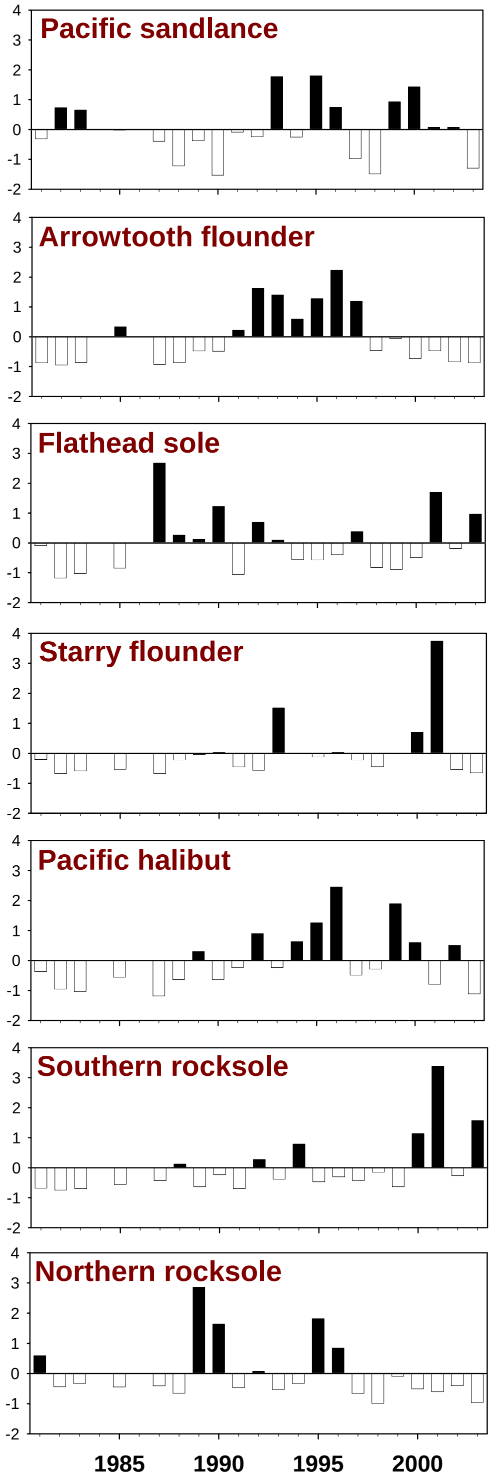


Table 10 continued.



Basin-Scale Variables

Pacific sandlance

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI							
FRESH							
SST1							
SST2			Neg				
PDOm							
NPI			Neg				
MEI							
PDOw							
VICw							

Arrowtooth flounder

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI							
FRESH				Neg			
SST1						Neg	
SST2						Pos	Pos
PDOm							
NPI				Neg			
MEI							
PDOw							
VICw							

Flathead sole

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI							
FRESH		Pos				Pos	
SST1							
SST2						Neg	
PDOm							
NPI							
MEI							
PDOw							
VICw							

Starry flounder

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI							
FRESH							
SST1				Pos			
SST2							
PDOm							
NPI							
MEI							
PDOw							
VICw							

Pacific halibut

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI							
FRESH		Neg					
SST1							
SST2							
PDOm							
NPI							
MEI				Neg			
PDOw							
VICw							

Southern rocksole

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI		Pos				Pos	
FRESH							
SST1				Pos			
SST2		Pos	Pos			Pos	
PDOm			Neg				
NPI				Neg			
MEI							
PDOw							
VICw							

Northern rocksole

	Jan	Feb	Mar	Apr	May	Feb2	Mar2
CUI		Pos	Neg				Neg
FRESH							
SST1		Neg	Neg				Neg
SST2							
PDOm							
NPI		Pos					
MEI							
PDOw							
VICw							

Local-Scale Variables

Pacific sandlance

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG		Neg				
UPWELL		Neg			Neg	
MIXING		Pos			Pos	
SSTanom						
T90						
FLOWKL8						
RI					Pos	

Arrowtooth flounder

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG					Neg	
UPWELL					Neg	
MIXING					Pos	
SSTanom						
T90						
FLOWKL8	Pos					
RI	Pos					

Flathead sole

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						
UPWELL						
MIXING					Neg	
SSTanom						
T90						
FLOWKL8					Neg	
RI						

Starry flounder

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						Neg
UPWELL						Neg
MIXING						
SSTanom			Pos			
T90						
FLOWKL8						
RI						

Pacific halibut

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						
UPWELL						
MIXING						
SSTanom						
T90						
FLOWKL8	Pos		Pos			
RI	Pos		Pos			

Southern rocksole

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG						
UPWELL						
MIXING						
SSTanom						
T90		Pos				
FLOWKL8						
RI						

Northern rocksole

	Mar1	Mar2	Apr1	Apr2	May1	May2
ALONG			Pos			
UPWELL		Neg		Neg		
MIXING	Pos					
SSTanom						
T90	Neg	Neg				
FLOWKL8			Pos	Pos		Pos
RI			Pos	Pos		